VII

STABILITY OF EXTERNAL FIXATORS USED FOR KNEE ARTHRODESIS AFTER FAILED KNEE ARTHROPLASTY

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Secondary arthrodesis as treatment for failed knee arthroplasty is being used increasingly. The usual method is sustained rigid external fixation. The fusion rate is low in cases with considerable metaphyseal bone loss and poor bone quality. Currently, the Hoffmann-Vidal fixator or comparable designs are preferred to the less stable Charnley single frame fixator. The standard Hoffmann-Vidal device uses only transverse percutaneous fixating pins and gives an anteroposterior bending stiffness that is considerably lower than the lateral bending stiffness. In the present study, external fixators were tested for stability in a material testing machine under standardized conditions using synthetic bones. The anteroposterior bending stiffness was significantly improved when sagittal pins connected to a ventral compression rod were added to a Hoffmann-Vidal fixator. Stiffness was still more improved when sagittal pins were connected to ventral frames as in a modification of the Hoffmann-Vidal or the similar Ace-Fischer fixator.

In the prearthroplasty era arthrodesis was successfully used for the treatment of gonarthropathies. The fusion rate was high if a compression arthrodesis was performed with a single external frame supplied with a Thomas' splint (Zimmer Orthopaedic Ltd., London, England) or plaster of Paris.[5] Currently, knee fusion is used primarily as a secondary measure in the treatment of knee arthroplasty failures. Fusion rates in such cases are considerably lower, especially when the removed endoprosthesis is of the hinged, intramedullar, fixed type.[3,7,10,13] It may be difficult to achieve stability with a single frame compression arthrodesis in such cases because of the metaphyseal bone loss reducing the bone-to-bone contact area. More stable external fixators with multiple pins and quadrilateral mountings are usually recommended.[10,11,13] The mechanical performance of one such fixator, the Hoffmann-Vidal external anchorage (Jacquet Orthopédie S.A., Geneva, Switzerland), has been thoroughly studied.[2,6,14] The anteroposterior bending stiffness was found to be low and was only one-fifth of the lateral bending stiffness. This might be a drawback when using the device for knee arthrodesis because of the sagittal action of the long lever arms of the femur and tibia.

The technical refinement of external fixators during recent years has been a reduction of the frame weight by using titanium and carbon rods. Furthermore, titanium oxide is so far the most inert material for bone.[1] Trilateral mounting and connecting joints that can be unlocked for adjustment in one plane at a time have made mounting and adjustment easier. Additional sagittal pins connected to a compression rod have been suggested as a way of improving anteroposterior stability.[4,8] Ventral frames enable the addition of sagittal pins to the usual set of transverse pins, which can also lead to a reduction of the number of connecting rods to three, as in the Ace-Fischer fixator (Ace Orthopedic Co., Los Angeles, California).[9]

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In the authors' experience, rigid fixation could not always be achieved when fusions following failed knee arthroplasty were performed with the Hoffmann-Vidal fixator.[11] Since this is the most commonly used fixator, the authors sought an improvement of its stability and designed a modification in the form of a ventral frame with sagittal pins and trilateral mounting.

The aim of this report is to test the biomechanical rigidity (the anteroposterior and lateral bending stiffness) of the standard Hoffmann-Vidal fixator and compare it with a Hoffmann-Vidal fixator with additional sagittal pins connected to a compression rod, a modified Hoffmann-Vidal fixator with additional sagittal pins connected to a ventral frame designed by the authors, and an Ace-Fischer fixator.

MATERIALS AND METHODS

The testing procedure was adopted from Briggs and Chao (1982).[2] Synthetic bone in the form of a solid bar, 20-cm long with a diameter of 2.8 cm, was made from die-cast Plastic Padding of the hard type (Plastic Padding H, Type Hard, 2-Comp., made by Plastic Padding Company, Sweden) (Figs. 1–5). Five external fixators were mounted on the synthetic bones and tested:

1. A standard Hoffman-Vidal fixator with quadrilateral mounting and six threaded transverse Steinmann pins (Figs. 1).[6]
2. The same as number 1, with the addition of two pairs of sagittal stainless steel pins clamped and connected with a ventral standard connecting rod. The sagittal pins were inserted at right angles to the transverse pins (Fig. 2).[4]
3. Sagittal and transverse pins as in number 2. Two side clamps and one ventral clamp were connected to a ventral frame, designed by the authors, using standard couplings. Trilateral mounting was thus arranged with one ventral and two posterior connecting rods fixed to the universal joints on the clamps (Fig. 3).
4. A standard Ace-Fischer fixator with a two-third circular ventral frame with trilateral mounting and stainless steel pins (Fig. 4).[9]
5. A standard Ace-Fischer fixator mounted as above but with titanium pins (Fig. 4).[9]

The diameter of the stainless steel pins was 4 mm. The long and short titanium pins were 5 mm at the blunt end and the long pins were 4 mm at their tapered end. Only threaded pins were used and the configuration for the two sets of three transverse pins was standardized (Fig. 5). The pin

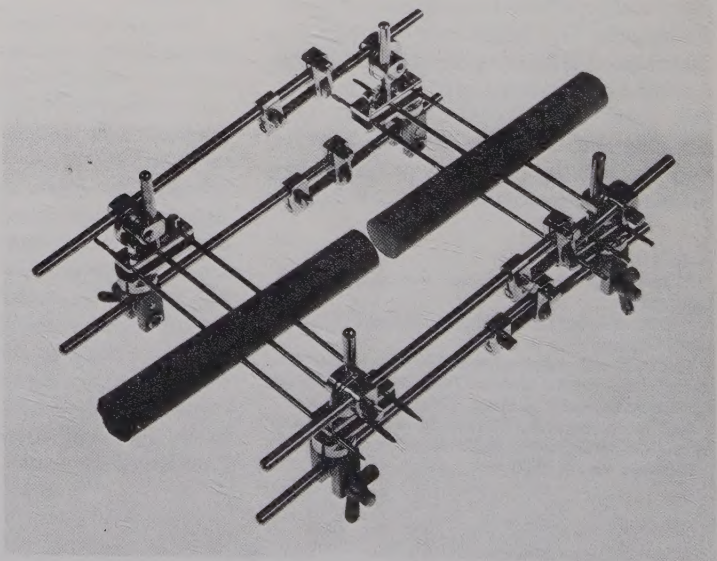

FIG. 1. A standard Hoffmann-Vidal fixator with quadrilateral mounting fixed to synthetic bones (Test object 1).

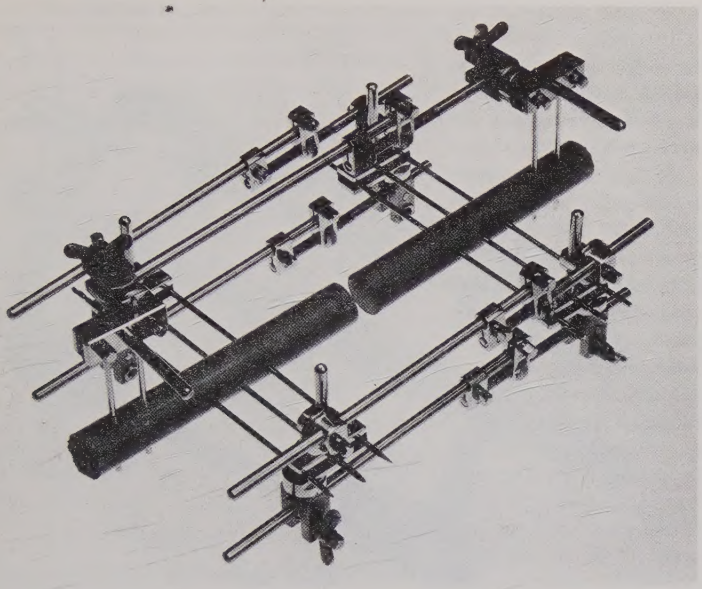

FIG. 2. A Hoffman-Vidal fixator with added sagittal pins and a ventral connecting rod (Test object 2).

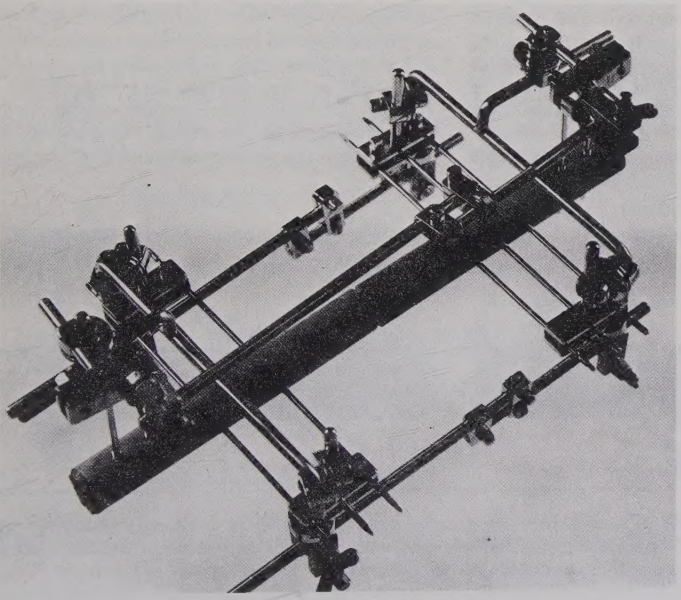

FIG. 3. A modified Hoffmann-Vidal fixator with ventral frames, sagittal pins, and trilateral mounting. The frames are of the authors' design (Test object 3).

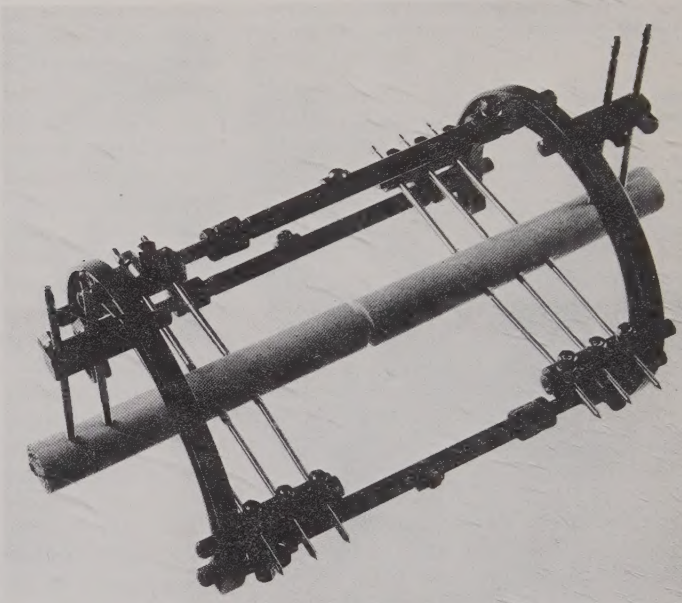

FIG. 4. An Ace-Fischer fixator with ventral frames, transverse and sagittal pins, and trilateral mounting (Test objects 4 and 5).

separation was 2.2 cm and sidebar separation was 16.2 cm. The lateral connecting rods were equidistant from the pins (3.0 cm). The two sagittal pins on each side were 2.2 cm apart and the most central sagittal pin was introduced 4.0 cm from the most peripheral transverse pin. This configuration was dictated by the geometry of the Ace-Fischer device. The ventral bar, when used, was clamped 6.0 cm from the synthetic bone (Fig. 5). Compression was not used. A free gap was left between the synthetic bones to simulate the condition often found in secondary knee fusion where the condyles are eroded and therefore add little to the stability (Fig. 5). To test four-point bending, a support was placed under the peripheral ends of the plastic bar 8.5 cm from the central transverse pin. The dis-

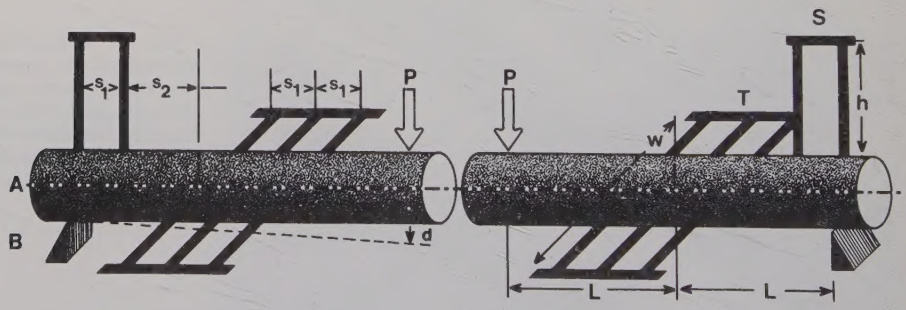

FIG. 5. The configuration of sagittal pins (S), transverse pins (T), synthetic bones (A), lateral support (B), bending load (P), and displacement (d) that was used when testing anteroposterior bending stiffness of external fixators. Connecting rods are not illustrated. Dimensions: S_1 = 2.2 cm, S_2 = 4.0 cm, W = 16.2 cm, H = 6.0 cm, and L = 8.5 cm. (Test objects 2–5. In test object 1 the sagittal pins were not used.)

placing force was measured with a load cell at the central end of the bar 8.5 cm from the central transverse pin. On the same end of the bone a strain gauge displacement transducer was placed (Fig. 5). An X-Y plotter recorded the load-deformation curves. An Instron testing machine (Instron Ltd., Bucks, Great Britain), which displaced the specimens at a constant speed of 0.2 cm/min, was used. The procedure was repeated three times in each setup and direction to ensure reproducible data. The test range was within 30 N to avoid permanent deformity.

Anteroposterior bending stiffness (K a-p) was defined as the anteroposterior bending force (P a-p) divided by the anteroposterior bone displacement (d a-p) (kilonewtons per centimeter).

Lateral bending stiffness (K lat) was defined as the lateral bending force (P lat) divided by the lateral bone displacement (d lat) (kilonewtons per centimeter).

RESULTS

The anteroposterior bending stiffness was significantly higher in external fixators with sagittal pins (2–5) than in the standard Hoffmann-Vidal fixator (1). The use of ventral frames (3–4) further significantly improved anteroposterior bending stiffness (Table 1).

Statistical tests used were from I. Bacos, Institute of Statistics, University of Lund, Lund, Sweden.

DISCUSSION

In secondary knee fusion after failed hinge knee arthroplasty, the condyles are often grossly deranged with large central cavities and poor bone quality. In such cases the fusion rate is usually low[3,7,10] and sustained rigid immobilization is recommended.[10–13] The long levers of femur and tibia, acting also in the sagittal plane, are unique for the knee arthrodesis, and the same bending forces are usually not seen in fracture treatment. This calls for a high anteroposterior bending stiffness if external fixation is used in cases of poor metaphyseal bone stock and explains why the Charnley single frame fixation has a lower fusion rate than a double frame fixator.[10,13] The Hoffmann-Vidal fixator has earlier been biomechanically tested and some measures were recommended to improve its stability.[2] The use of threaded instead of smooth transverse pins has been recommended. These add stability mainly in the lateral plane, where the sliding motion along the peripheral pins is hampered. The geometry of the fixator, apart from pin group separation, influences the stability. Side bar separation greatly affects anteroposterior bending stiffness, and in the Hoffmann-Vidal fixator this should be kept as small as possible. In fixators with a fixed ventral frame, side bar separation cannot be adjusted, and frames of different sizes have to be available. In the Hoffmann-Vidal fixator the number of connecting rods influences the stability—four rods are usually used. With ventral frames, stability is adequate with only

TABLE 1. Summary of Results

					Bending Stiffness (kN/cm)	
No.	*Type of Fixator*	*Mounting*	*Sagittal Pins*	*Pin Material*	*Antero-posterior* (mean ± SD)*	*Lateral (mean ± SD)*
1	Hoffmann-Vidal	Quadrilateral	No	Stainless steel	0.077 ± 0.001	1.0 ± 0.009
2	Hoffmann-Vidal	Quadrilateral and ventral	Yes	Stainless steel	0.29 ± 0.000	0.88 ± 0.004
3	Hoffmann-Vidal and ventral frames	Trilateral	Yes	Stainless steel	0.39 ± 0.004	0.82 ± 0.015
4	Ace-Fischer	Trilateral	Yes	Stainless steel	0.47 ± 0.002	0.83 ± 0.000
5	Ace-Fischer	Trilateral	Yes	Titanium	0.51 ± 0.003	0.79 ± 0.006

* K a-p 1–5: Student's *t*-test ($p < 0.001$), Wilcoxon-Mann-Whitney ($p = 0.05$).
kN = kilonewtons.

three connecting rods. Furthermore, the trilateral mounting reduces the risk of creating internal stress during adjustment. Larger pin diameter and wider pin separation add to the stability, but this is not a standard alternative and has not been tested in the present study. For this reason pin diameter, pin separation, side bar separation and pin group separation were not altered during the testing procedure. Differences in bending stiffness in this study, compared with those in other studies on Hoffmann-Vidal fixators, are due to differences in the geometrical setup, which were necessary for the maintenance of the same standardized geometry in both the Hoffmann-Vidal and Ace-Fischer fixators.

The low anteroposterior bending stiffness of the Hoffmann-Vidal fixator, compared with the lateral bending stiffness, was verified in this study. Rigidity was improved when sagittal pins were added. The highest anteroposterior bending stiffness was found when sagittal pins were combined with ventral frames. Most probably, a more even distribution of the bending stiffness between the sagittal plane and the lateral plane could be achieved if two transverse and three sagittal pins in each bone are used.

There may also be an indication for the addition of ventral frames and sagittal pins in early ambulating patients with femoral or tibial shaft fractures for whom improved anteroposterior stiffness is beneficial.

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